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2018, pp. 159-163. https://doi.org/10.56577/FFC-69.159

in:

Las Cruces Country III, Mack, Greg H.; Hampton, Brian A.; Ramos, Frank C.; Witcher, James C.; Ulmer-Scholle, Dana S., New Mexico Geological Society 69th Annual Fall Field Conference Guidebook, 218 p. https://doi.org/10.56577/FFC-69

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New Mexico Geological Society Guidebook, 69th Field Conference, Las Cruces Country III, 2018, p. 159-163.

AGE RELATIONSHIPS OF IGNEOUS ROCKS IN THE DOÑA ANA MOUNTAINS

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Abstract—Igneous rocks in the Doña Ana Mountains encompass ages that range from at least 43.1 to 33.2 Ma. Rocks of the Palm Park formation are ~43 Ma and are intruded by younger Doña Ana Rhyolite at 36 Ma. Rhyolite of nearby Goat Mountain is of similar age but different composition. Regional dikes, likely related to the Summerford Syenite Sill, are ~33 Ma and significantly post-date Doña Ana and Goat Mountain rhyolitic volcanism. These dikes have different compositions compared to the Doña Ana Rhyolite and are emplaced after the formation of the Doña Ana caldera.

INTRODUCTION

The Doña Ana Mountains, located due north of Las Cruces, NM (Fig. 1), result from late Eocene- early Oligocene-related volcanism and caldera formation, and subsequent Neogene normal faulting related to crustal extension associated with southern Rio Grande rifting. The range is primarily composed of a variety of volcanic, plutonic, and sedimentary rocks spanning ages from Pennsylvanian and Permian to Oligocene. Tectonically, the Doña Ana Mountains are subdivided into three blocks (Seager and Mack, this volume) separated by faults or fracture zones. The northern block is composed primarily of upper Pennsylvanian and lower Permian sedimentary rocks intruded by the younger, early Oligocene Summerford Mountain syenite sill (Seager et al., 1976). The central block is composed of Eocene andesites and dacites of the Palm Park Formation, whereas the southern block is composed mainly of latest Eocene-early Oligocene rhyolitic ash flow tuffs, rhyolite flows and domes, and dikes related to the Doña Ana caldera.

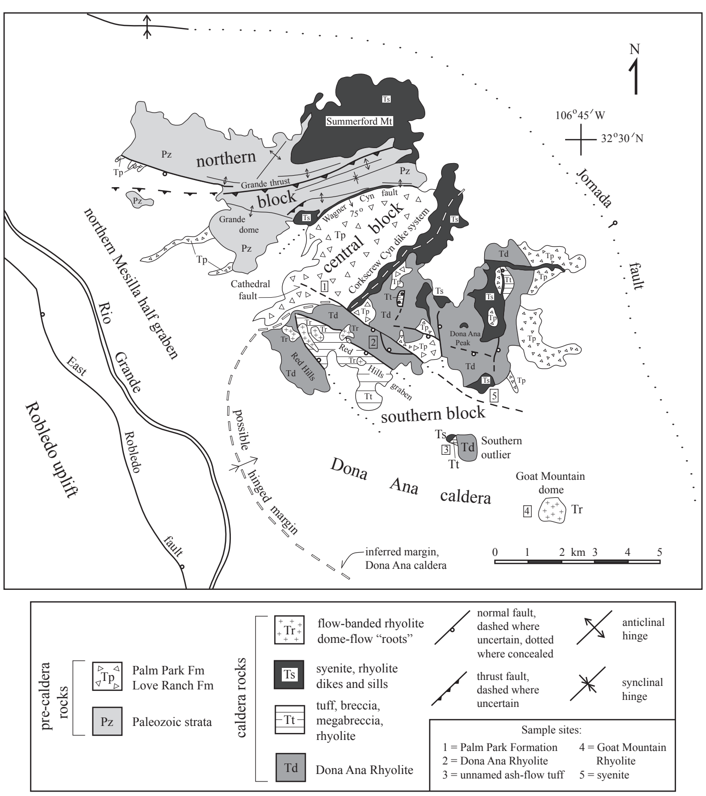

FIGURE 1. General geological map of the Doña Ana Mountains showing locations of whole rocks sampled for feldspar in this study (modified from Seager and Mack, this volume).

The relative age of igneous rocks in the Doña Ana Mountains have been established by field mapping (Seager et al., 1976). However, few radiogenic ages are available from the range and those that exist were analyzed over 25 years ago (Seager et al. 1976; McIntosh et al., 1991). Here we obtain $^{40}Ar/^{39}Ar$ ages from:

1. An andesitic lava flow from the Palm Park formation (DAA plagioclase).
2. The Doña Ana Rhyolite (DAR sanidine), an ash flow tuff that erupted during the collapse of the Doña Ana caldera (Seager et al., 1976; Seager and Mack this volume).
3. An unnamed ash-flow tuff that is ~65 m stratigraphically above the Doña Ana Rhyolite (DA upper biotite) and is considered to have been erupted after caldera collapse (Seager and Mack, this volume; Mack et al., this volume, first day road log).
4. The Goat Mountain Rhyolite (DAG Goat Mountain sanidine), an isolated, conical outcrop in the southern part of the range that may represent either an eruption vent or a flow-banded dome (Seager and Mack, this volume).
5. A syenite dike (DAMP K-feldspar) in the southern part of the range that presumably is correlated to the Summerford Mountain syenite sill (Seager et al., 1976; Seager and Mack, this volume).

METHODS

Whole rocks were collected from select locations in the Doña Ana Mountains that included Palm Park Formation andesite (DAA), Doña Ana caldera fill rhyolite (DAR), and dikes related to the Summerford Mountain syenite (DAMP, Table 1). Additional samples were collected from tuffs exposed in a satellite exposure to the south and from Goat Mountain (DAG). Whole rocks were crushed and sieved for a range of particles sizes. These different sizes were then inspected for feldspars and biotite. Sieve fractions with the largest feldspars were chosen and individual feldspars were hand picked. Feldspars, including sanidine, orthoclase, and plagioclase, were then etched in 10% hydrofluoric acid for 5–20 minute intervals. Samples were then rinsed in distilled water and sonicated to obtain crystals free of adhering materials. Crystals chosen for $^{40}Ar/^{39}Ar$ analyses ranged from 0.2 to 2 mg.

Mineral separates were loaded into machined Al discs and irradiated for 8 hours (NM-288) at the USGS TRIGA Reactor in Denver (CO). Fish Canyon Tuff sanidine (FC-2) was used as a flux monitor and assigned an age of 28.201 Ma (Kuiper et al., 2008). The ^{40}K total decay constant of $5.463e^{-10}/a$ was used (Min et al., 2000). Argon isotopes for the feldspars were measured using a ThermoScientific ARGUS IV mass spectrometer (Jan) while the biotite was analyzed using a Helix MC plus mass spectrometer. The multi-collector configuration used for the ARGUS VI analyses was: ^{40}Ar-H1, ^{39}Ar-Ax, ^{38}Ar-L1, ^{37}Ar-L2, and ^{36}Ar-L3. Amplifiers used for H1, AX, and L2 Faradays were $1e^{13}$ Ohm, the L1 Faraday was $1e^{14}$ Ohm, and L3 used a CDD ion counter with a deadtime of 14ns. For the Helix, the configuration was ^{40}Ar-H2, ^{39}Ar-H1, ^{38}Ar-AX, ^{37}Ar-L1, and ^{36}Ar-L2. Amplifiers used for H2, H1, AX, L1 Faradays were $1e^{12}$ Ohm, L2 used a CDD ion counter with a deadtime of 20ns. Feldspars were step-heated or fused for 30-40 seconds using a 75W Photon Machines CO_2 laser whereas the biotite was heated with a 50W Photon Machines diode laser. Reactive gases were removed with various combinations of SAES NP-10, GP-50 and D50 getters. Mass spectrometer sensitivity for the ARGUS VI is $6e^{-17}$ mol/fA and for the Helix $3e^{-16}$ mol/fA. Typical total system blank and backgrounds were 5±20%, 0.2±10%, 0.05±12%, 0.25±5%, and 0.04±10%, x 10^{-17} moles for masses 40, 39, 38, 37, and 36, respectively for the ARGUS VI runs and 20±2%, 0.4±100%, 0.6±60%, 0.5±75%, and 0.08±5%, x 10^{-17} moles for masses 40, 39, 38, 37, and 36, respectively for the Helix runs. Correction factors for interfering reactions were determined by analysis of K-glass and CaF2. J-factors were determined to precisions of ~±0.02% and used CO_2 laser fusions of at least 6 crystals from multiple radial positions around irradiation trays.

RESULTS

Palm Park Formation

Sixteen, single to 3 crystal aliquots of plagioclase from a Palm Park lava flow in the upper portion of Cleofas Canyon were step-heated in 3 increments. Three analyses yield complex spectra and apparent ages greater than 100 Ma (Data Supplement). Thirteen analyses yield flat age spectra with plateau ages between 41.6 and 46.9 Ma with 10 yielding a normal distribution and weighted mean age of 43.05±0.28 Ma (Fig. 2). An attempt to date sanidines from a dacitic unit in the Palm Park Formation lower down Cleofas Canyon (i.e., to the west) was unsuccessful because the crystals were highly altered.

Doña Ana Caldera

In the southern Doña Ana Mountains block, sanidines were dated from the Doña Ana Rhyolite and the Goat Mountain Rhyolite, whereas biotite was dated from a post-caldera-collapse ash flow tuff and plutonic potassium feldspar from a syenite dike related to the Summerford syenite sill. Sixteen of 18 single sanidine crystals from the Doña Ana Rhyolite yield an age of 36.04±0.01 Ma (Fig. 3). Both a slightly young grain (perhaps argon loss) and a slightly old grain (perhaps a xenocryst) were omitted from the age calculation. Biotite was dated from the upper of two, post-caldera ash flow tuffs from a southern outlier exposure of the Doña Ana Mountains. Biotite yields an age spectrum with initially climbing ages between 32 and 36 Ma with an overall flat segment with a weighted mean age 36.68±0.06 Ma (Fig. 4). This sample is stratigraphically younger than the Doña Ana Rhyolite but the biotite yields an

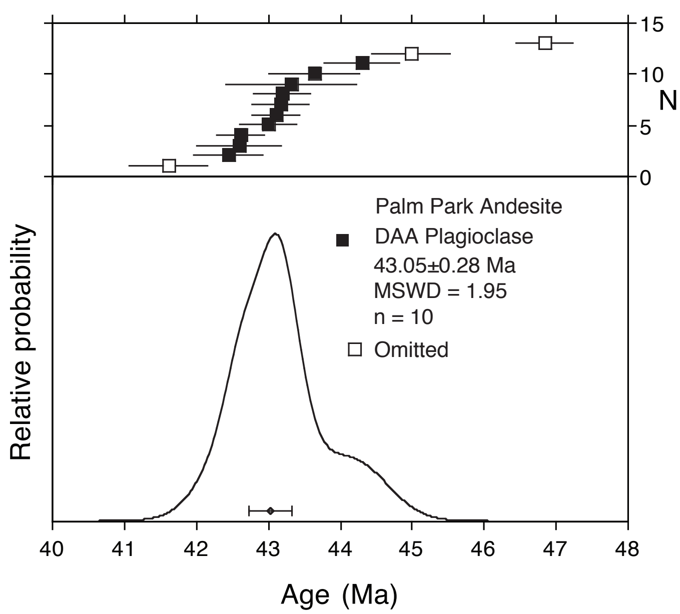

FIGURE 2. Age probability diagram showing replicate plagioclase plateau ages from the Doña Ana Andesite (DAA). Although the total range of ages span from >100 to 41.6 Ma, ten analyses yield a 43.05 Ma age.

TABLE 1. Table showing sample identifiers, formations, and locations of Doña Ana Mountains whole rocks.

Sample ID	DAA	DAD	DAR	DAMP	DAG
Formation	Palm Park	Palm Park	Doña Ana	Doña Ana	Goat Mountain
Latitude	32.462	32.457	32.438	32.439	32.405
Longitude	-106.839	-106.853	-106.838	-106.784	-106.761

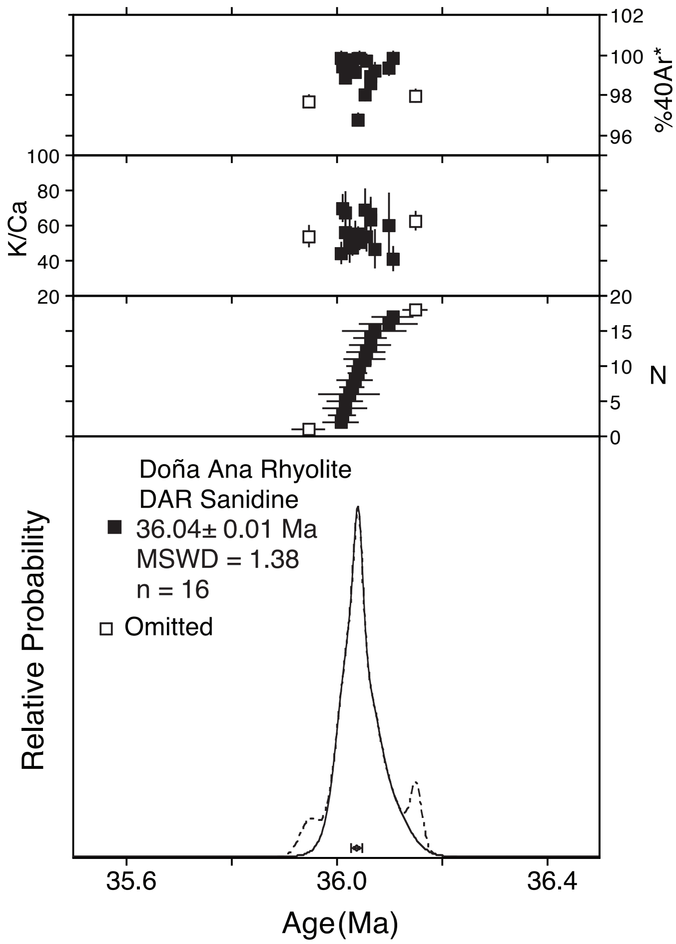

FIGURE 3. Relative probability, K/Ca, and radiogenic yield diagrams showing results of single crystal, sanidine argon data from the Doña Ana Rhyolite (DAR). With two crystals omitted, sixteen crystals yield an age of 36.04 Ma.

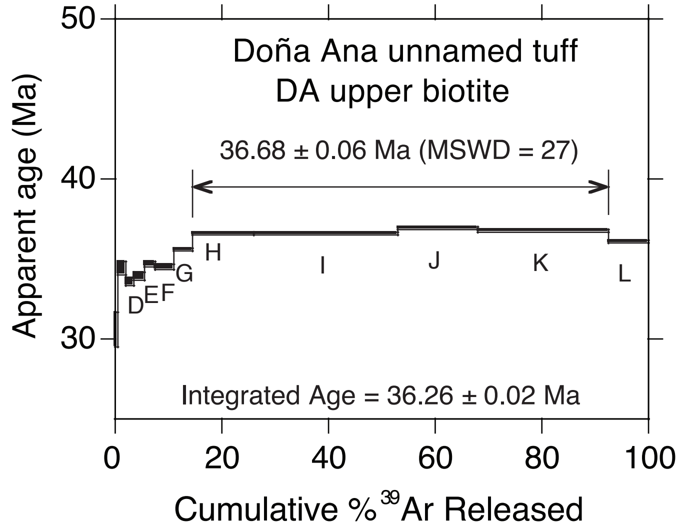

FIGURE 4. Age spectrum for biotite showing ages from the upper unit of two unnamed tuffs from a southern outlier exposure of the Doña Ana Mountains. Note, the 36.68 Ma age is older than the underlying Doña Ana Rhyolite (36.04 Ma), which indicates an inaccurate biotite age likely resulting from the presence of excess argon

older age. In cases where co-existing biotite and sanidine are dated from ignimbrites, biotite is commonly older and is suspected to contain excess argon thereby yielding an inaccurate age (Hora et al., 2010). Therefore, the biotite age indicates that this upper unit is Eocene, however in detail, the age is not accurate as it is ca. 0.7 Ma older than the Doña Ana Rhyolite.

Age spectrum analysis of a potassium feldspar separate from the syenite (DAMP) is characterized by initially climbing ages with a somewhat noisy flat section for the majority of the spectrum with a weighed mean age of 33.2±0.2 Ma (Fig. 5). Finally for Goat Mountain, 26 single feldspars were analyzed (Fig. 6). Four grains yield ages between 127 and 540 Ma and are xenocrystic plagioclase. The remaining 22 grains are sanidine with ages ranging between 35.7 and 36.4 Ma. Four grains with relatively young and low precision ages, along with one grain at 36.4 Ma, are excluded from the 17 feldspars that yield a weighted mean age of 35.98±0.02 Ma (Fig. 6).

DISCUSSION

Palm Park Formation

The plagioclase crystal age (43.05±0.28 Ma) in the central block of the Doña Ana Mountains suggests that Palm Park rocks in Cleofas Canyon are likely from the lower part of the formation. Although present in various localities throughout southern New Mexico, the Palm Park Formation in the Doña Ana Mountains is commonly highly altered and composed of both dacitic and andesitic lavas. Plagioclase crystals were obtained from fresh andesite associated with a lava flow in the upper reaches of Cleofas Canyon. Attempts to obtain fresh feldspars from additional outcrops (i.e., Palm Park dacite) were however unsuccessful, which reflects the highly and variably altered nature of Palm Park rocks in the central block of the Doña Ana Mountains. The $^{40}Ar/^{39}Ar$ plagioclase date (43.05 Ma) obtained is generally older than the age of zircon (41.6 Ma; Creitz and

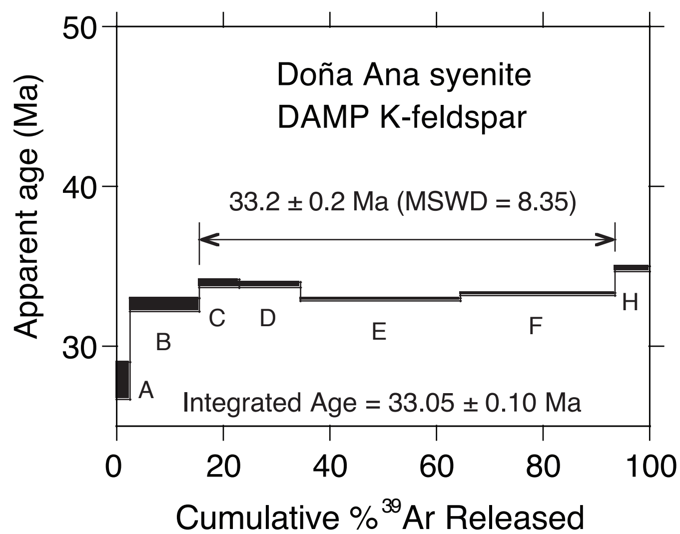

FIGURE 5. Age spectrum showing ages from an orthoclase separate from a syenite dike (DAMP) in which ages rise to 33.2 Ma for over 70% of the gas released.

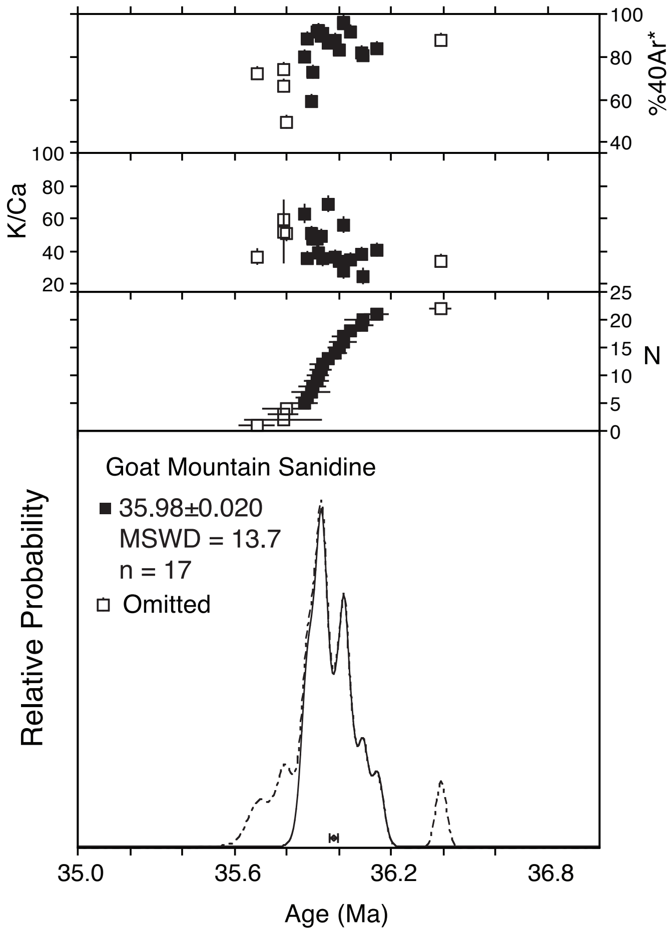

FIGURE 6. Relative probability, K/Ca, and radiogenic yield diagrams showing single crystal, sanidine argon data for the Goat Mountain Rhyolite (DAG). Seventeen sanidine crystals yield an age of 35.98 Ma.

Hampton, this volume) sampled from nearby Palm Park rocks (i.e., in Cleofas Canyon). This range likely results from the range in age for which Palm Park volcanism was active, such that the section of Palm Park Formation in the Doña Ana Mountains likely encompasses at least ~1–1.5 my of geologic history.

Doña Ana Rhyolite

The distinctive red Doña Ana caldera fill rhyolite covers much of the southern block of the Doña Ana Mountains. The Doña Ana Rhyolite at 36.04±0.01 Ma is significantly older than the 33.0 Ma (no uncertainties provided) K/Ar age of Seager et al. (1976) and is analytically indistinguishable to the age (35.95±0.11 Ma) of McIntosh et al. (1991) when normalized to the Fish Canyon standard age of 28.201 Ma. Our new result is much more precise and represents the best age for the Doña Ana Rhyolite and indicates that caldera related activity was focused in the Doña Ana Mountains after activity (>36.1 Ma) at the nearby Organ Mountains, located ~30 km to the southeast, had waned (Seager, 1981; McIntosh et al., 1991; Zimmerer and McIntosh, 2013; Rioux et al., 2016). The Goat Mountain Rhyolite is indistinguishable in age to the Doña Ana Rhyolite but is physically and chemically distinctive (Ramos et al., this volume). As such, volcanic activity at this age involved a range of magma compositions.

Unnamed Ash-flow Tuff

A biotite crystal age of the upper of two tuffs located in the southern outlier of the Doña Ana Mountains southern block is older than many of the $^{40}Ar/^{39}Ar$ ages of Doña Ana Mountain rocks, including those that underlie the tuffs. Mapping confirms that both of these tuffs cap an ~80-m-thick succession of ash flow tuffs containing green pumices and other volcaniclastic facies that overlie the 36.04 Ma Doña Ana Rhyolite. As mentioned above, the biotite age is likely affected by excess argon and thus too old, but the tuffs are nonetheless likely related to the main eruptive phase of the Doña Ana caldera.

Goat Mountain Rhyolite

The Goat Mountain rhyolite is 35.98±0.02 Ma and has features that suggest a shallow intrusive origin (Seager and Mack, this volume). These features may contribute to the somewhat scattered distribution of apparent ages for the Goat Mountain sample that are perhaps related to a more complex cooling history. In any case, identical ages of Goat Mountain Rhyolite and Doña Ana Rhyolite may indicate that a series of variable, highly-evolved magmas were likely simultaneously present during Doña Ana Mountain volcanic activity and caldera formation.

Syenite Dike

Syenite dikes in the southern Doña Ana Mountains caldera block are generally assumed to be related to the more northern 33.7 Ma (K/Ar age, no uncertainty given, Seager et al., 1976) Summerfold Mountain syenite sill. In the Doña Ana Mountains southern block, the 33.2±0.2 Ma dike age is significantly younger than all other volcanic materials in the Doña Ana Mountains. Haga (1994) suggested that the intrusive and extrusive rocks might be originating from the same magma chamber, however the nearly 3 my discordance between the ages of the Doña Ana Rhyolite and syenite appears to preclude such an interpretation. The presence of syenite dikes and sills across all blocks of the Doña Ana Mountains attest to continued magmatism in the region significantly after the bulk of extrusive related volcanic activity and caldera formation.

CONCLUSIONS

Oligocene-Eocene magmatic activity in the Doña Ana Mountains involved highly-evolved magma compositions that intruded and disrupted pre-existing Palm Park Formation andesites/dacites and Pennsylvanian and Permian sedimentary rocks. Age variations of nearby Organ Mountains volcanism in this region are consistent with concentrated volcanic activity occurring after the main episode of volcanism in the Organ Mountains had ceased. As such, the diverse ages and magma compositions are consistent with a caldera complex that was not related to the Organs, and likely resulted from a shift in magmatism to the Doña Ana Mountains.

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*Agave lechuguill*a, above, from the Organ Mountains and a barrel cactus (right, *Ferocactus* sp.) from near the dam at Leasburg Dam State Park. Photograph by Dana S. Ulmer-Scholle.